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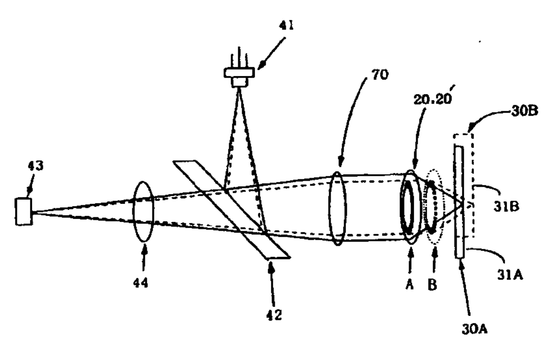
(54) Optical pickup having an objective lens compatible with a plurality of optical disk formats

(57) An optical pickup compatible with a plurality of optical recording media each using light of a different wavelength. The optical pickup includes at least one light source (41), an objective lens (20, 20') having a function of focusing light emitted from the light source (41) into the optimal light spot on an information recording surface of one of the plurality of the optical recording media (30), and a light detector (43) to detect light transmitted through the objective lens (20, 20') after being reflected from the information recording surface of the optical recording medium (30) on which the light spot is formed. The objective lens (20, 20') has an inner area, an annular lens area and an outer area such that the annular lens area divides the inner area from the outer area and has a ring shape centered at a vertex. The inner area, the annular lens area and the outer area have aspherical surface shapes to focus light transmitted through the inner area and the outer area into a single light spot by which information can be read from the information recording surface of a relatively thin first optical recording medium (30A) and scatter light transmitted through the annular lens area located between the inner area and the outer area so that information cannot be read from the information recording surface of the first optical recording medium (30A), during reproduction of the first optical recording medium. The inner area and the annular lens area transmit light into a single light spot by which information can be read from the information recording surface of a relatively thick second optical recording medium (30B) and scatters light transmitted through the outer lens area so that information cannot be read from the information recording surface of the second optical recording medium (30B), during reproduction of the second optical recording medium (30B).

FIG. 6



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Description

The present invention relates to an optical pickup including an objective lens having a function of forming an optical spot on an information recording surface of optical recording media of different formats, and more particularly, to an optical pickup having an objective lens which is compatibly used in a plurality of optical disks each having a different format, such as a digital versatile disk (DVD), a CD-Recordable (CD-R), CD-Rewritable (CD-RW), a Compact Disc (CD) and a Laser Disk (LD).

A recording medium for recording and reproducing information such as video, audio or data at high density, is a disk, a card or a tape. However, a disk-type recording medium is primarily used. Recently, an optical disk system has been developed in the form of an LD, a CD and a DVD. However, when optical disks having respectively different format, such as DVD, CD-R, CD, CD-RW and LD are compatibly used, optical aberration occurs due to the variation of disk thickness and wavelength. Thus, an optical pickup which is compatible with the different formats of the disks as well as removes the above-mentioned optical aberration has been actively studied. In the result of such a study, optical pickups which are compatible with the different formats have been fabricated.

Figures 1A and 1B show a part of a conventional optical pickup which is compatible with different formats. Figure 1A shows a case where light is focused on a thin optical disk and Figure 1B is a case where light is focused on a thick optical disk. In Figures 1A and 1B, a reference numeral 1 denotes a hologram lens, 2 denotes a refractive objective lens, 3a denotes a thin optical disk, and 3b denotes a thick optical disk. Light 4 output from an unshown light source is diffracted by a grating (lattice) pattern 11 of the hologram lens 1, to accordingly generate non-diffracted zero-order light 40 and diffracted first-order light 41, respectively. The non-diffracted zero-order light 40 is focused on an information recording surface of an optical disk 3a by the objective lens 2. The diffracted first-order light 41 is focused on an information recording surface of an optical disk 3b by the objective lens 2. Therefore, the optical pickup shown in Figures 1A and 1B uses the non-diffracted zero-order light 40 and the diffracted first-order light 41 to record information on or read the information from the optical disks 3a and 3b of different thicknesses, respectively.

Another conventional technology is disclosed in Japanese Patent Laid-open Publication No. Heisei 7-302437, published on November 14, 1995. An objective lens of an optical head apparatus disclosed in the above publication has, from the centre of the objective lens an odd-numbered region(s) having a focal point congruent with an information recording surface of a thin optical disk, and an even-numbered region(s) having a focal point congruent with an information recording surface of a thick optical disk. Thus, in the case of the thin optical disk, light transmitted through the odd-numbered region(s) of the objective lens is used to read information from the thin optical disk. Also, in the case of the thick optical disk, light transmitted through the even-numbered region(s) of the objective lens is used to read information from the thick optical disk.

However, since the optical pickup shown in Figures 1A and 1B divides the incident light into zero order light and first order light, the efficiency of a light use is lowered. That is, since the incident light is divided into zero order light and first order light by the hologram lens 1, only the zero-order light or the first-order light is used to record the information on or read the information from the optical disk, and the optical pickup uses only 15% or so of the incident light, to thereby lower the light use efficiency. Also, according to the thickness of the used optical disk, only one of the zero-order light and the first-order light reflected from the corresponding optical disk 3a or 3b contains actually read information. Thus, the light having no information functions as noise in a light detection operation with respect to the light containing information. The above problem can be overcome by processing the hologram lens 1 of the lens device. However, when working the hologram lens 1, an etching process for producing a fine hologram pattern requires a high precision. Thus, the manufacturing cost increases.

In the case of the prior art disclosed in Japanese Patent Laid-open Publication No. Heisei 7-302437, the light transmitted through only one of the odd-numbered region(s) and the even-numbered region(s) is used. As a result, the light use efficiency is lowered. Also, since the number of the focal points is always two, the light having no information functions as noise during the light detection, which makes it difficult to detect information from the light reflected from the optical disk.

With a view to solve or reduce the above problem it is an aim of preferred embodiments of the present invention to provide an optical pickup which has an excellent signal detection function independent of a disk format thereof.

It is another aim to provide an objective lens which compatibly is used with at least two substrates having respectively different thicknesses.

Additional aims and advantages of the invention will be set forth in part in the description which follows and, in part, will be obvious from the description, or may be learned by practice of the invention.

According to a first aspect of the invention, there is provided an objective lens compatible with at least first and second media having respective different thicknesses and information recording surfaces which store information, the objective lens comprising: an inner area, an annular lens area and an outer area centered at a vertex, the annular lens area having a ring shape and dividing the inner area from the outer area, wherein the inner area, the annular lens area and the outer area have aspherical shapes so that, in the case of reading the first medium, light transmitted through

the inner area and the outer area is focused into a single light spot by which information is read from the information recording surface of the first medium and light transmitted through the annular lens area is scattered so as not to be focused on the information recording surface of the first medium and, in the case of reading the second medium, the light transmitted through the inner area and the annular lens area is focused into a single light spot by which information is read from the information recording surface of the second medium and light transmitted through the outer lens area is scattered so as not to be focused on the information recording surface of the second medium and wherein the second medium is thicker than the first medium.

According to a second aspect of the invention, there is provided an objective lens for use in an optical device compatible with at least first and second media having respective different thicknesses and information recording surfaces which store information, the objective lens having a plurality of portions having different optical characteristics, wherein said plurality of lens portions include: a first portion to focus a light emitted from a light source onto a given optical medium independent of the thickness of the optical medium; a second portion to focus light emitted from the light source onto said optical medium if said optical medium is the first optical medium which has a first predetermined thickness; and a third portion to focus said light emitted from said light source onto said optical medium if said optical medium is the second optical medium which has a second predetermined thickness; and a surface of the second portion forms a step difference with the surface of one of the first and third portions.

In the objective lens of the second aspect, the first portion preferably comprises an inner area, the second portion comprises an annular lens area and the third portion comprises an outer area.

The objective lens of the first or second aspects may include the following preferred features in any logical combination:

(i) a difference AZ between a focal distance of the annular lens area and that of the inner area is preferably the same as a defocusing amount determined by the following relationship:

$$\Delta Z=-(2W_{40})/(NA)^2$$

wherein NA is a numerical aperture in the inner area and W_{40} is a spherical aberration coefficient when the second medium is used.

(ii) a surface of the annular lens area preferably forms a step difference for the surface of one of the inner and outer areas.

(iii) the surface of the annular lens area may form the step difference with the surface of the inner area, wherein the step difference is a value such that a light path difference between the light passing through the inner area and the light passing through the annular lens area is an integer multiple of a wavelength of the light emitted from the light source.

(iv) the surface of the annular lens area may form the step difference with the surface of the outer area, wherein the step difference is a value such that a light path difference between the light passing through the inner area and the light passing through the annular lens area is an integer multiple of a wavelength of the light emitted from the light source.

According to a third aspect, there is provided an optical pickup in an optical device compatible with at least first and second optical recording media having different thicknesses and including an objective lens according to the first or second aspects, the optical pickup further comprising: a first light source to emit light toward said objective lens, the objective lens being arranged to focus the first light emitted from the light source into a single light spot on the information recording surface of a given optical recording medium; and a light detector to detect transmitted through the objective lens after being reflected from the information recording surface of the optical recording medium on which the light spot is focused.

In the optical pickup the objective lens may have a working distance in such a manner that the light transmitted through the inner area is focused into a single light spot having minimum optical aberration on the information recording surface of the second medium during reading of the second medium.

The aspherical surface shape of the inner area is preferably such that the light transmitted through the inner area is focused into a single light spot on the information recording surface of the first optical medium, and the same light is focused into an optical spot having minimum optical aberration on the information recording surface of the second optical medium during reproduction of the second optical medium with said working distance.

The aspherical shape of the annular lens area may be such that the light transmitted through the annular lens area

is focused into a single light spot having no spherical aberration on the information recording surface of the second optical recording medium during reproduction of the second optical recording medium having a thick substrate.

The optical pickup may further comprise at least a second light source, said second light source emitting light of a different wavelength to light emitted from the first light source.

The optical pickup may further comprise a beam splitter having a beam splitting characteristic with respect to each of the plurality of the beams respectively emitted from the first light source and the at least second light source.

In an objective lens according to the first or second aspect or an optical pickup device or the third aspect, the inner area of the objective lens preferably has a numerical aperture value NA which satisfies the following equation: $0.8\lambda/NA \sim$ spot size where λ represents the wavelength of light emitted from the light source and the spot size is a size of a spot that the light passing through the objective lens forms on a disk.

The objective lens may have a defocused coefficient W_{20} which minimises an optical aberration according to the following equation: $W_{20}=-W_{40}$, wherein W_{40} is a spherical aberration coefficient produced due to a difference in the first and second thicknesses.

A defocus amount ΔZ of the objective lens preferably follows the following equation: $\Delta Z=-(2W_{40})/(NA)^2$, wherein NA is a numerical aperture value of the inner area.

The pickup may further comprise: a separation unit to separate incident light transmitted from said light source from light reflected by the disk.

The optical pickup may further comprise: a collimating lens disposed in a linear path between the objective lens and the light detector to collimate the incident light separated by the separation unit and to transmit the reflected light from the disk towards the separation unit; and a light detection lens to focus the reflected light passing through the separation unit toward the detector.

According to another aspect of the invention, there is provided an optical pickup in an optical device and compatible with a plurality of optical recording media having different thicknesses, the optical pickup comprising: a light source to emit light; an objective lens to focus the light emitted from the light source into a single light spot on an information recording surface of one of the plurality of the optical recording media; and a light detector to detect light transmitted through the objective lens after being reflected from the information recording surface of the one optical recording medium on which the light spot is focused; wherein said objective lens has an inner area, an annular lens area and an outer area centered at a vertex, the annular lens area having a ring shape and dividing the inner area from the outer area; and the inner area, the annular lens area and the outer area have aspherical surface shapes so as to focus the light transmitted through the inner area and the outer area into the single light spot by which information is read from the information recording surface of the one optical recording medium and to scatter the light transmitted through the annular lens area formed between the inner area and the outer area so that the scattered light is not focused on the information recording surface of the one optical recording medium if the one optical recording medium is a first optical recording medium having a first thickness, and so as to focus the light transmitted through the inner area and the annular lens area into the single light spot by which information is read from the information recording surface of the one optical recording medium and to scatter the light transmitted through the outer lens area so that the scattered light is not focused on the information recording surface of the one optical recording medium if the one optical recording medium is a second optical recording medium having a second thickness greater than the first thickness.

Preferably, said objective lens has a working distance in such a manner that the light transmitted through the inner area is focused into the single light spot having minimum optical aberration on the information recording surface of the second optical recording medium during reproduction of the second optical medium.

Preferably, the aspherical surface shape of the inner area is such that the light transmitted through the inner area is focused into a single light spot on the information recording surface of the first optical recording medium during reproduction of the first optical medium, and the same light is focused into an optical spot having minimum optical aberration on the information recording surface of the second optical recording medium during reproduction of the second optical medium with said working distance.

Preferably, the aspherical shape of the annular lens area is such that the light transmitted through the annular lens area is focused into the single light spot having no spherical aberration on the information recording surface of the second optical recording medium during reproduction of the second optical medium having a thick substrate.

A difference ΔZ between a focal distance of the annular lens area and that of the inner area preferably becomes a defocusing amount determined by the following relationship:

$$\Delta Z=-(2W_{40})/(NA)^2$$

wherein NA is a numerical aperture in the inner area and W_{40} is a spherical aberration coefficient which the inner area has during reproduction of the second optical recording medium.

The numerical aperture of the inner area preferably maintains a value of 0.3 at a minimum.

The annular lens area of said objective lens may have a numerical aperture such that the inner area and the annular lens area form the single light spot on the information recording surface of the second optical recording medium during reproduction of information from the second optical medium.

The inner area, the annular lens area and the outer area may be formed on a lens surface of the objective lens facing the light source side of the objective lens.

Preferably, an imaginary surface extending the aspherical surface of the annular lens area is spaced apart from the vertex on the aspherical surface of the inner area.

Preferably, a width of the annular lens area ranges between about 100 and about 300μm.

Preferably, a surface area of the annular lens area is at least 10% of an incident surface of said objective lens of the light from the light source.

The pickup may further comprise at least one additional light source, each of the light source and the at least one additional light source emitting light of different wavelengths.

The optical pickup may further comprise a beam splitter having a beam splitting characteristic with respect to each of the plurality of the beams respectively emitted from the light source and the at least one additional light source.

The first optical recording medium is preferably a digital versatile disk (DVD) and the second optical recording medium is one of a compact disk (CD) and a laser disk (LD), when said light source emits the light having a wavelength which is adapted for the digital versatile disk (DVD).

The pickup may further comprise at least one additional light source, wherein said first optical recording medium is a digital versatile disk (DVD) and said second optical recording medium is one of a compact disk (CD), a compact disk recordable (CD-R), CD-Rewritable (CD-RW) and a laser disk (LD), when a first one of the light sources emitting the light has a wavelength which is adapted for the digital versatile disk (DVD) and a second one of the light sources has a wavelength which is adapted for the compact disk recordable (CD-R) are used.

Preferably, the light detector is a single detector used to detect the light from said first and second optical recording media as optical information, when at least two of the plurality of light sources are used and said first and second optical recording media are compatibly reproduced.

Preferably, said objective lens has a step difference which is formed in a region where the annular lens area and the inner area contact each other and the step difference makes a light path difference between the light transmitted through the inner area of said objective lens and the light transmitted through the annular lens area to have an integer multiple of a wavelength of the light emitted from the light source, during reproduction of information from the second optical recording medium.

The height of said step difference may be about 1.0-1.5μm.

Said objective lens may have a step difference which is formed in a region where the annular lens area and the outer area contact each other and makes a light path difference between the light transmitted through the inner area of said objective lens and the light transmitted through the annular lens area to have an integer multiple of a wavelength of the light emitted from the light source, during reproduction of information from the second optical recording medium.

According to a yet further aspect of the invention, there is provided an objective lens compatible with at least two substrates having respectively different thicknesses and information recording surfaces which store information, the objective lens comprising: an inner area, an annular lens area and an outer area centered at a vertex, the annular lens area having a ring shape and dividing the inner area from the outer area; wherein the inner area, the annular lens area and the outer area have aspherical surface shapes so as to focus light transmitted through the inner area and the outer area into a single light spot by which information is read from the information recording surface of a first one of the at least two substrates which has a first thickness and to scatter the light transmitted through the annular lens area formed between the inner area and the outer area so that the scattered light is not focused on the information recording surface of the first substrate, when the first substrate is to be used, and so as to focus the light transmitted through the inner area and the annular lens area into the single light spot by which the information is read from the information recording surface of a second one of the at least two substrates which has a second thickness greater than the first thickness and to scatter the light transmitted through the outer lens area so that the scattered light is not focused on the information recording surface of the second substrate, when the second substrate is to be used.

A difference ΔZ between a focal distance of the annular lens area and that of the inner area is preferably the same as a defocusing amount determined by the following relationship:

$$\Delta Z=-(2W_{40})/(NA)^2$$

wherein NA is a numerical aperture in the inner area and W_{40} is a spherical aberration coefficient when the second substrate is to be used.

Said objective lens may have a step difference which is formed in a region where the annular lens area and the inner area contact each other and the step difference makes a light path difference between the light transmitted through

the inner area of said objective lens and the light transmitted through the annular lens area to have an integer multiple of a wavelength of the light emitted from the light source, when the second substrate is to be used.

Said objective lens may have a step difference which is formed in a region where the annular lens area and the outer area contact each other and the step difference makes a light path difference between the light transmitted through the inner area of said objective lens and the light transmitted through the annular lens area to have an integer multiple of a wavelength of the light emitted from the light source, when the second substrate is to be used.

According to still another aspect of the invention, there is provided an optical pickup device in an optical device and compatible with disks having different thicknesses, the optical pickup device comprising: a light source: an objective lens, facing one of the disks which is placed in the optical device, having a light passing region divided into inner, annular lens and outer regions respectively corresponding to a near axis area, an intermediate axis area and a far axis area of incident light, wherein curvatures of the central and periphery regions are optimized for the one disk if the one disk has a first thickness and a curvature of the annular region is optimized for the one disk if the one disk has a second thickness greater than the first thickness; a photo detector for detecting light reflected from the one disk; and a separation unit to separate the incident light transmitted from said light source from the reflected light reflected by the one disk.

Preferably, the inner area has a numerical aperture value NA according to the following equation:

$$0.8\lambda \sim \text{spot size}$$

where λ is a wavelength of the light emitted from the light source and the spot size is a size of a spot that the light passing through the objective lens forms on the one disk.

The wavelength may be 650nm and NA is at least 0.37.

Preferably, the annular lens area has an aspherical surface shape by which the annular lens area corrects optical aberration of the light from the light source passing therethrough at a position of a focal point of the inner area.

The objective lens may have a defocus coefficient W_{20} which minimizes an optical aberration according to the following equation:

$$W_{20}=-W_{40};$$

wherein W_{40} is a spherical aberration coefficient produced due to a difference in the first and second thicknesses.

A defocus amount ΔZ of the objective lens preferably follows the following equation:

$$\Delta Z=-(2W_{40})/(NA)^2 \fallingdotseq -8.3\mu m;$$

wherein NA is a numerical aperture value of the inner area.

A width of the annular lens area may form at least 10% of an incident surface of the objective lens through which the light from the light source passes.

A width of the annular lens area is preferably between 100 and 300μm.

Preferably, a surface of the annular lens area protrudes from surfaces of the inner and outer areas.

Preferably, a surface of the annular lens area may be cutout from the surfaces of the inner and outer areas.

A surface of the annular lens area may form a step difference with a surface of one of the inner and outer areas.

Preferably, the surface of the annular lens area forms the step difference with the surface of the inner area, wherein the step difference is a value such that a light path difference between the light passing through the inner area and the light passing through the annular lens area is an integer multiple of a wavelength of the light emitted from the light source.

Preferably, the surface of the annular lens area forms the step difference with the surface of the outer area, wherein the step difference is a value such that a light path difference between the light passing through the inner area and the light passing through the annular lens area is an integer multiple of a wavelength of the light emitted from the light source.

The pickup may comprise: a collimating lens disposed in a linear path between the objective lens and the light detector, to collimate the incident light separated by the separation unit and to transmit the reflected light from the one disk toward the separation unit; and a light detection lens to focus the reflected light passing through the separation unit toward the photodetector; wherein the separation unit is a beam splitter.

The pickup may further comprise: a unit on which the light source and the photo detector are formed adjacent to each other; the separation unit being a holographic beam splitter; and a collimating lens to collimate the light passing through the holographic beam splitter from the light source and to transmit the reflected light from the one disk toward the holographic beam splitter; wherein the holographic beam splitter directs the reflected light toward the photodetector.

The optical pickup may further comprise a quarter wave plate disposed between the holographic beam splitter and the collimating lens.

The holographic beam splitter may be a polarizing hologram.

The pickup may further comprise: a unit on which the light source and the photo detector are formed adjacent to each other; the separation unit may be a holographic beam splitter; and a collimating lens to collimate the light passing through the holographic beam splitter from the light source and to transmit the reflected light from the one disk toward the holographic beam splitter; wherein the holographic beam splitter directs the reflected light toward the photo detector.

According to a still further aspect of the invention, there is provided an optical pickup device in an optical device and which reads information from an optical recording medium, the optical pickup device comprising: a first light source to emit a first light; a second light source to emit a second light, wherein only one of the first and second light sources emits the first and second lights, respectively, at a given time; an objective lens to receive the one of the first and second lights emitted from the corresponding one of the first and second light sources, and to focus the one of the first and second lights emitted toward the optical recording medium and pass light reflected from the optical recording medium; and a photo detector to receive the light reflected from the optical recording medium and passed through the objective lens, to reproduce the information.

Preferably, the first light source emits the first light if the optical recording medium has a first thickness and the second light source emits the second light if the optical recording medium has a second thickness greater than the first thickness.

Preferably, the first light has a first frequency and the second light has a second frequency different from the first frequency.

The objective lens may be a single lens.

The objective lens preferably includes a light passing region divided into inner, annular lens and outer regions, wherein curvatures of the central and periphery regions are optimized for the optical recording medium if the optical recording medium has a first thickness and a curvature of the annular region is optimized for the optical recording medium if the optical recording medium has a second thickness which is preferably greater than the first thickness.

A surface of the annular lens area preferably forms a step difference with a surface of one of the inner and outer areas.

The optical pickup device may further comprise: a first beam splitter to transmit the first light from the first light source and to reflect the second light from the second light source; a second beam splitter to transmit the first light transmitted through the first beam splitter and the second light reflected by the first beam splitter; and a collimating lens to collimate the first light and reflected second light transmitted through the second beam splitter, and transmit the collimated light to the objective lens; wherein the second beam splitter reflects the first and second lights reflected from the optical recording medium.

The device may further comprise a first beam splitter to transmit the first light from the first light source and to reflect the second light from the second light source; a second beam splitter to transmit the first light transmitted through the first beam splitter and the second light reflected by the first beam splitter; and a collimating lens to collimate the first light and reflected second light transmitted through the second beam splitter, and transmit the collimated light to the objective lens; wherein the second beam splitter reflects the first and second lights reflected from the optical recording medium.

The optical pickup device may further comprise: a first beam splitter to reflect the first light from the first light source; a second beam splitter to transmit the first light reflected by the first beam splitter and reflect the second light reflected by the first beam splitter; and a collimating lens to collimate the first light and reflected second light transmitted through the second beam splitter, and transmit the collimated light toward the objective lens; wherein the first and second beam splitters transmit the first and second lights reflected from the optical recording medium to the photo detector.

According to another aspect, there is provided an optical pickup device in an optical device and which reads information from and optical recording medium, the optical pickup device comprising: a first light source to emit a first light; a second light source to emit a second light, wherein only one of the first and second light sources emits the first and second lights, respectively, at a given time; an objective lens to receive the one of the first and second lights emitted from the corresponding one of the first and second light sources, and to focus the one of the first and second lights emitted toward the optical recording medium and pass light reflected from the optical recording medium; a first photo detector to receive the first light reflected from the optical recording medium and passed through the objective lens, to reproduce the information; and a second photo detector to receive the second light reflected from the optical recording medium and passed through the objective lens, to reproduce the information.

Preferably, the first light source emits the first light if the optical recording medium has a first thickness and the second light source emits the second light if the optical recording medium has a second thickness greater than the first thickness.

Preferably, the first light has a first frequency and the second light has a second frequency different from the first frequency.

The objective lens may include a light passing region divided into inner, annular lens and outer regions, wherein curvatures of the central and periphery regions are optimized for the optical recording medium if the optical recording medium has a first thickness and a curvature of the annular region is optimized for the optical recording medium if the optical recording medium has a second thickness greater than the first thickness.

Preferably, a surface of the annular lens area forms a step difference with a surface of one of the inner and outer areas.

The optical pickup may further comprise: a beam splitter to transmit the first light from the first light source and to reflect the second light from the second light source; and a collimating lens to collimate the first light transmitted through the beam splitter and the second light reflected by the second beam splitter, and transmit the collimated light to the objective lens; wherein the beam splitter transmits the first light reflected from the optical recording medium to the first photo detector and reflects the second light reflected from the optical recording medium to the second photo detector.

According to a still further aspect, there is provided an objective lens for use in an optical device compatible with different types of optical memory media, said objective lens having a plurality of portions having different optical characteristics, wherein one of said plurality of lens portions focuses said light onto one of said optical memory media independent of the type of said one optical memory medium; wherein said plurality of lens portions include a first portion to focus a light emitted from a light source onto said one optical memory medium independent of a thickness of said one optical memory medium, a second portion to focus said light emitted from the light source onto said one optical memory medium if said optical memory medium has a first predetermined thickness, and a third portion to focus said light emitted from said light source onto said one optical memory medium if said optical memory medium has a second predetermined thickness which is different from said first predetermined thickness; and a surface of the second portion forms a step difference with a surface of one of the first and third portions.

Preferably, the surface of the second portion forms the step difference with the surface of the first portion, wherein the step difference is a value such that alight path difference between the light passing through the first portion and the light passing through the second portion is an integer multiple of a wavelength of the light emitted from the light source.

Alternatively, the surface of the second portion may form the step difference with the surface of the third portion, wherein the step difference is a value such that a light path difference between the light passing through the first portion and the light passing through the second portion is an integer multiple of a wavelength of the light emitted from the light source.

For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings, in which:

Figures 1A and 1B show a conventional optical pickup having a hologram lens and a refractive objective lens;

Figure 2A shows that an objective lens according to first and second embodiments of the present invention forms an optical spot on an information recording surface of a thin optical disk;

Figure 2B shows that the objective lens according to the first and second embodiments of the present invention forms an optical spot on an information recording surface of a thick optical disk;

Figure 2C shows an objective lens according to the first and second embodiments of the present invention as viewed from a light source, which shows sections of an inner area, an annular lens area and an outer area of the objective lens;

Figure 2D shows an enlarged annular lens area portion of an ideal annular lens of the present invention;

Figure 3A shows longitudinal spherical aberration of the objective lens according to the first embodiment of the present invention during readout of a thick optical medium;

Figure 3B shows wavefront aberration of the objective lens according to the first embodiment of the present invention during readout of a thick optical medium;

Figure 4 shows an objective lens according to the first embodiment of the present invention;

Figure 5 shows an enlarged annular lens portion of the objective lens according to the second embodiment of the present invention;

Figure 6 shows a first type optical system of an optical pickup having a single light source adopting an objective

lens according the first and second embodiments of the present invention;

Figure 7 shows a modification of the optical system of the optical pickup shown in Figure 6;

Figure 8A shows a second type of optical pickup having an objective lens, two light sources and a single light detector according to the first and second embodiments of the present invention;

Figure 8B shows a modification of the optical pickup shown in Figure 8A;

Figure 9 shows a third type of optical pickup having an objective lens, two light sources and two light detectors according to the first and second embodiments of the present invention;

Figure 10 shows distribution of the light beams in the light detector when a thin optical disk is read by using the optical pickup according to the first and second embodiments of the present invention; and

Figure 11 shows distribution of the light beams in the light detector when a thick optical disk is read by using the objective lens according to the first and second embodiments of the present invention.

Reference will now be made in detail to the present preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The embodiments are described below in order to explain the present invention by referring to the Figures.

Figures 2A through 2D show an objective lens according to the present invention. Figure 2A shows optical paths when a working distance of the objective lens 20 is "WD1" during readout of a thin optical disk 30A. Figure 2B shows optical paths when a working distance of the objective lens 20 is "WD2" during readout of a thick optical disk 30B. Figure 2C shows an objective lens 20 viewed from a light source, which shows that a lens surface 22 lying in the light source side of the objective lens 20 is divided into an inner area (central region) A1, an annular lens area (intermediate region) A2 and an outer area (periphery region) A3. Figure 2D is an enlarged view of the portion of the annular lens area A2 of the objective lens 20, where the objective lens 20 is ideally manufactured.

In the objective lens 20 according to the first embodiment of the present invention, the lens surface 22 which lies in the light source side of the objective lens 20 is divided into the inner area A1, the annular lens area A2 and the outer area A3, by the annular lens area A2 having a ring form such as an elliptical or circular shape with a vertex V1 of the lens surface 22 in the center. Here, the vertex V1 is a point where the axis of the objective lens 20 intersects the lens surface 22 of the light source side. The inner area A1 and the outer area A3 have aspherical surface shapes which are optimized to form a best focal point on the information recording surface 31A of the thin optical disk 30A. Also, the inner area A1 is fabricated to generate a little spherical aberration on the information recording surface 31B of the thick optical disk 30B, but to have a sufficiently small spherical aberration for readout of the thick optical disk 30B. Particularly, the inner area A1 has a numerical aperture NA meeting the following relationship 1 to provide an optimized optical spot for reproducing the thick optical disk 30B such as an existing CD. The inner area A1, annular lens area A2, and outer area A3 respectively correspond to a near axis region, an intermediate axis region and a far axis region of incident light.

When light of 650nm wavelength is used, it is preferable that the numerical aperture NA of the objective lens 20 is 0.37 or more to reproduce the existing CD.

$$0.8\lambda/NA \sim \text{spot size} \qquad (1)$$

Here, λ represents the wavelength of the light, and NA represents the numerical aperture of the inner area A1. Assuming that a working distance of the objective lens 20 is "WD1" where the best focal point is formed by the inner area A1 and the outer area A3, the light (rays) transmitted through the inner area A1 and the outer A3 form the optimal spot on the information recording surface 31A of the thin optical disk 30A with respect to the working distance "WD1" and do not generate spherical aberration. Also, when the light transmitted through the inner area A1 of the objective lens 20 is used, the existing optical disk 30B such as a relatively thick CD is reproduced. This technology has been disclosed in Korean patent application No. 96-3605. However, a numerical aperture not less than 0.4 is required to reproduce an optical disk which uses a smaller sized spot such as an LD among the existing optical disks. To make large NA above 0.37, when the annular lens area A2 has an aspherical surface extending the aspherical surface shape of the inner area A1, the light transmitted through the annular lens area A2 during reproduction of the LD generates a larger optical aberration to such a degree that the LD cannot be reproduced. Therefore, the annular lens area A2 corrects such optical aberration, and has an aspherical surface shape by which the light transmitted through the annular

lens area A2 corrects the optical aberration at a best position where a focal point is formed by the inner area A1.

Figure 2B shows an optical path during reproduction of the thick optical disk 30B, and shows that the light transmitted through the outer area A3 does not form a spot on the optical disk and is scattered and the light transmitted through the areas A1 and A2 are focused on the thick disk surface 31B. Meanwhile, when the working distance of the objective lens 20 is "WD2", the light transmitted through the annular lens area A2 is scattered at the information recording surface 31A of the optical disk 30A. The solid lines in Figure 2A show the optical paths of the light transmitted through the inner area A1 and the outer area A3 when the working distance is "WD1". The dotted line shows the optical path of the light transmitted through the annular lens area A2 in which the light is scattered.

Figure 3A is a graph showing aberration for explaining a working distance and optical longitudinal spherical aberration of the objective lens 20 during readout of a thick optical disk 30B. Since the inner area A1 has spherical aberration when the objective lens 20 reproduces the thick optical disk 30B, the objective lens 20 is optically defocused, that is, the working distance is adjusted, to thereby have a minimal value of the optical aberration. A spherical aberration coefficient W_{40} produced due to the difference of a disk thickness between the thin optical disk 30A and the thick optical disk 30B meets the following equation 2.

$$W_{40} = \frac{n^2-1}{8n_3}\, d(NA)^4 \fallingdotseq 0.6\mu m \qquad (2)$$

Generally, the optical aberration including spherical aberration is expressed as the following equation (3).

$$W = W_{20}h^2 + W_{40}h^4 \qquad (3)$$

Here, W_{20} is a defocus coefficient and h is a marginal (light) ray height.
The square root of the optical aberration meets the following equation 4.

$$\sigma^2 w = \sqrt{(\overline{W}^2 - (\overline{W})^2}) = \frac{1}{12}[W_{20} + W_{40}]^2 + \frac{1}{180}\, W_{40}{}^2$$

Here,

$$\overline{W}^2 = \frac{1}{3}\, W_{20}{}^2 + \frac{1}{2} W_{20} W_{40} + \frac{1}{5}\, W_{40}{}^2,$$

$$\overline{W} = \frac{1}{2}\, W_{20} + \frac{1}{3}\, W_{40}$$

Therefore, the condition of the defocus coefficient which minimizes the optical aberration is $W_{20}=-W_{40}$, and the actual defocus amount complies with the following equation (5).

$$\Delta Z = -\frac{2W_{40}}{(NA)^2} \fallingdotseq -8.3\ \mu m \qquad (5)$$

Here, the variation of the numerical aperture (NA) of the inner area, the disk refractive index (n) and the disk thickness (d) are as follows: NA=0.38, n=1.58 and d=0.6mm. If the annular lens area A2 is designed so that a best spot is formed and spherical aberration does not occur with respect to the thick optical disk 30B being defocussed by 8.3μm, the longitudinal spherical aberration graph as shown in Figure 3A can be obtained. In this case, the difference between a focal length formed by the inner area A1 and a focal length formed by the annular lens area A2 becomes 8.3μm owing to the defocus amount of 8.3μm at the optical axis. And the focal length is 3.3025mm for the inner area A1 and 3.3111mm for the annular lens area A2 according to the calculation by a commercial program (s/w) for optics. The 8.3μm is a result from a third order calculation by hand, but 8.6μm is a result from a high order calculation including the third order by using the optical (s/w) program.

If the working distance of the objective lens 20 is changed from "WD1" to "WD2" which makes the optical aberration by the light transmitted through the annular lens area A2 into substantially zero, the light transmitted through the annular lens area A2 forms the optical path shown as the solid lines in Figure 2B, and forms the optimal spot on the information recording surface 31B of the thick optical disk 30B. When the working distance "WD2" is the optimal working distance

for reproduction of the thick optical disk 30B, the annular lens area A2 increases efficiency of utilization of the light used and increases the numerical aperture as well. In this case, the inner area A1 maintains spherical aberration which is sufficiently small for reproduction of the thick optical disk 30B. The spherical aberration generated by the inner area A1 is minimized and total wavefront aberration is about 0.07λrms. Thus, the light transmitted through the inner area A1 and the annular lens area A2 forms a spot having a reduced size of 15% or more without increasing the optical aberration on the information recording surface 31B of the thick optical disk 30B, as compared with a case when the annular lens area A2 has the same aspherical surface shape as that of the inner area A1. Thus, it is possible to reproduce an optical recording medium such as an existing LD requiring a high density, as well as a CD. In this case, the light transmitted through the outer area A3 is scattered and does not influence the optical spot formed on the information recording surface 31B of the thick optical disk 30B. The optical path of the light transmitted through the outer area A3 is shown as the dotted lines in Figure 2B. Thus, a single optical spot can be formed on the information recording surface 31B. Examples of the working distances described above and shown in Figures 2A and 2B are WD1=1.897mm and WD2=1.525mm.

When the recorded information is read, the thin optical disk 30A uses the light of the relatively short wavelength, while the thick optical disk 30B uses both the light of the short wavelength and the relatively long wavelength. Therefore, when the thin optical disk 30A is a DVD and the thick optical disk 30B is a CD, an LD, CD-RW or a CD-R, the inner area A1 and the outer area A3 have the aspherical surface shapes optimized to the information recording surface of the DVD, and the inner area A1 and the annular lens area A2 have the aspherical surface shapes where aberration is corrected and the working distance is optimized so that the information can be reproduced with respect to the information recording surface of the CD, the LD or CD-RW or the CD-R. The annular lens area A2 among the areas A1, A2 and A3 has an aspherical surface shape determined by the following equation (6) expressing the aspherical surface.

$$Z(h) = \frac{h^2/R}{1+\sqrt{(1-(1+K)h^2/R^2)}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10} + Z_{offset} \qquad (6)$$

In the above equation (6), a function "Z" is a distance from the surface perpendicular to the optical axis and passing through the vertex V1 of the objective lens 20 to the lens surface 22 lying on the light source side of the objective lens 20. A variable "h" is a distance from the axis of the objective lens 20 to a particular point perpendicular to the axis. A constant "R" is a curvature which becomes a reference to determine an aspherical surface shape. Z_{offset} is a parameter which is newly introduced to express a step difference between the annular lens area A2 and the inner area A1. Since the equation (6) is well known to a person who has an ordinary skill in the art, a detailed description thereof will be omitted. The annular lens area A2 has a protruded shape or a recessed shape when compared with the inner area A1 and the outer area A3. The annular lens area A2 of the protruded shape is enlarged and shown in Figure 2D. The aspherical surface shapes possessed by the inner area A1 and the outer area A3 can be expressed by removing the offset component Z_{offset} in the equation (6). The width of the annular lens area A2 is determined to provide the spot optimized for reproducing the relatively thick optical disk, and occupies at least 10% of an incident surface 22 of the objective lens 20 to which the light is incident from the light source. In case of a quantitative expression, the width of the annular lens area A2 has a range between about 100 and 300μm.

The data obtained to provide the optimal aspherical surface shapes to the area A1, A2 and A3 is represented in the following table.

Table

LENS SURFACE	CURVATURE	ASPHERICAL SURFACE COEFFICIENT	THICKNESS	REFRACTIVE INDEX
INNER AREA (A1)/ OUTER AREA (A3)	2.13482	K: -0.425667 A: -0.822095E-03 B: -0.249645E-03 C: -0.106803E-03 D: -0.194864E-03 Z_{offset}: 0.0	1.795	1.5864

Table (continued)

LENS SURFACE	CURVATURE	ASPHERICAL SURFACE COEFFICIENT	THICKNESS	REFRACTIVE INDEX
ANNULAR LENS AREA (A2)	2.14101	K: -0.425667 A: -0.362745E-03 B: -0.259541E-03 C: -0.665620E-03 D: -0.620804E-03 Z_{offset}: -0.0012	1.795	1.5864
LENS SURFACE (24) TOWARD OPTICAL DISK	-14.39337	K: 8.578602 A: 0.897734E-02 B: -0.341346E-02 C: -0.762226E-03 D: -0.665163E-04		
OPTICAL DISK	0		1.2/0.6	1.58

When the aspherical surface shapes of the areas A1, A2 and A3 are determined by the equation (6) and the above Table, the imaginary surface which extends from the aspherical surface of the annular lens area A2 expressed as the dotted line in Figure 4 becomes farther than the aspherical surface of the inner area A1 from the vertex V1 of the objective lens 20.

However, to easily form the areas A1, A2 and A3 of the aspherical surface shapes on the lens surface lying on the light source side, it is preferable that the annular lens area A2 is worked after working the inner area A1 and the outer area A3 primarily. Thus, the ring-shaped annular lens area A2 has a step difference at a region of contact with the inner area A1 contacts or the outer area A3.

Figure 4 shows an objective lens 20 which is worked so that a step difference exists in a region where the inner area A1 contacts the annular lens area A2. Figure 5 shows an objective lens 20' which is worked so that a step difference exists in a region where the annular lens area A2 contacts the outer area A3. Such step differences generate aberration due to a light path difference between the light passing through the inner area A1 and the annular lens area A2. The step differences have a height by which optical aberration due to the light path difference between the light passing through the inner area A1 and the annular lens area A2 can be removed with respect to the light of a relatively long wavelength emitted from the light source or the light for reproduction of the thick optical disk. Particularly, the height of the step difference is determined so that a light path difference between the light transmitted through the annular lens area A2 and the light transmitted through the inner area A1 of the objective lens 20 becomes an integer multiple of the wavelength of the used light as shown in Figure 3B. The step difference height is determined to be a value by which the optical aberration due to the light path difference can be removed by taking the offset Z_{offset} in the equation (6) and the width of the annular lens area A2 into consideration. Preferably, the step difference height is approximately 1μm~-1.5μm according to the refractive index of the objective lens.

Figure 6 shows a first type of optical pickup having a single light source adopting an objective lens 20 or 20' according to the first and second embodiments of the present invention. The optical pickup shown in Figure 6 has a typical optical system, which is compatible with optical disks of various different formats using the identical wavelength of light, by using the objective lens 20 or 20' according to the first and second embodiments of the present invention. The optical source 41 emits the laser beam of a particular wavelength. A light detector 43 is designed so that the light transmitted through the outer area A3 of the objective lens 20 or 20' is not detected during reproduction of the thick optical disk 30B. That is, the light detector 43 is designed so that only the light transmitted through the inner area A1 and the annular lens area A2 of the objective lens 20 or 20' is detected during reproduction of information from the thick optical disk 30B.

For clarity, a case where the optical pickup of Figure 6 includes the objective lens 20 or 20' and the optical source 41 emits the light of 650nm wavelength will be described. The (light) rays of 650nm wavelength emitted from the light source 41 are reflected from a beam splitter 42. The beam splitter 42 reflects about 50% of the incident light and the reflected rays become substantially parallel by a collimating lens 70. Since the (light) rays incident from the light source toward the objective lens 20 or 20' can be made into substantially parallel light using the collimating lens 70, a more

stable read operation can be performed. When a reproduction operation with respect to a thin disk 30A, for example, a DVD is performed, the (light) rays transmitted through the collimating lens 70 are focused in the form of a beam spot on an information recording surface 31A of the thin disk 30A by the objective lens 20 or 20'. In this case, the objective lens 20 or 20' has a working distance "WD1" and is shown as a solid line in Figure 6 at position A. Therefore, the rays of 650nm wavelength form a light path shown as the solid line in Figure 6. The light reflected from the information recording surface 31 A of the thin disk 30A is transmitted through the objective lens 20 or 20' and the collimating lens 70, and then is incident on the beam splitter 42. The beam splitter 42 transmits about 50% of the incident light and the transmitted light is focused into the light detector 43 by a light detection lens 44. Here, the light transmitted through the inner area A1 and the outer area A3 of the objective lens 20 or 20' forms a spot of a particular size on the information recording surface 31A of the thin disk 30A, by which information can be read from the information recording surface 31A of the thin disk 30A. Meanwhile, the light transmitted through the annular lens area A2 of the objective lens 20 or 20' forms a band in a scattered form at a position deviated by about 5pm on the disk 31B from the position of the spot formed by the light transmitted through the inner area Al and the outer area A3. Thus, the light transmitted through the annular lens area A2 is not detected by the light detector 43 and does not function as noise with respect to an effective reproduction signal during reproduction of data from the thin disk 30A.

When a reproduction operation with respect to a thick disk 30b, for example, a CD or LD, is performed, the light transmitted through the collimating lens 70 is focused in the form of a beam spot on an information recording surface 31B of the thick disk 30B by the objective lens 20 or 20' at position B. In this case, the objective lens 20 or 20' has a working distance "WD2" and is shown as a dotted line in Figure 6. Therefore, the light forms an optical path shown as the dotted line in Figure 6. Here, the light transmitted through the inner area A1 and the annular lens area A2 of the objective lens 20 or 20' forms a spot of a size on the information recording surface 31B of the thick disk 30B, by which information can be read from the information recording surface 31B of the thick disk 30B. Meanwhile, the light transmitted through the outer area A3 of the objective lens 20 or 20' forms a spot having a relatively weak intensity and lying at a position deviated from the position of the spot formed by the light transmitted through the inner area Al and the annular lens area A2. Thus, the light detector 43 can read information from the thick disk 30B using the light transmitted through the inner area A1 and the annular lens area A2 of the objective lens 20 or 20'.

In more detail, the light transmitted through the inner area A1 generates spherical aberration on the information recording surface 31B of the thick disk 30B. However, the spherical aberration has a sufficiently small amount to read the signal from the thick disk 30B and the minimized optical aberration is maintained by defocusing the light by the amount of the spherical aberration at the optical axis. The lens curvature and an aspherical surface coefficient of the annular lens area A2 are corrected for a non-aberration optical system at the state where the working distance is adjusted to about 10μm, so that additional spherical aberration is not generated. Accordingly, the numerical aperture increases without increasing the optical aberration and the size of the spot is reduced. Thus, an existing optical disk such as an LD requiring a higher-density than a CD can be reproduced. For reference, a spot size of about 1.2μm is needed to reproduce the LD, and that of about 1.4μm is needed to reproduce the CD. A spot size of about 0.9μm is needed to reproduce the DVD. As a result, the present invention can reproduce the various disks such as DVD, LD and CD, using a simple optical pickup.

Figure 10 shows a distribution of the light in the light detector 43 when information from a thin disk 30A is reproduced according to first and second embodiments of the present invention. In Figure 10, dark portions are due to the light transmitted through the inner area A1 and the outer area A3 of the objective lens 20 or 20' and are detected as an efficient reproduction signal. However, bright portions between the dark portions represent that the light transmitted through the annular lens area A2 of the objective lens 20 or 20' is not detected in the light detector 43 and is not detected as an efficient reproduction signal. Figure 11 shows distribution of the light beams in the light detector 43 when information from a thick optical disk 30B is reproduced using the objective lens 20 or 20' according to the present invention. A notation "B1" shows a distribution of the light transmitted through the inner area A1 in the light detector, "B2" shows a distribution of the light transmitted through the annular lens area A2, and "B3" shows a distribution of the light transmitted through the outer area A3. The light forming the B1 and B2 distributions as shown in Figure 11 is detected as an efficient signal in the light detector 43, and the light forming the B3 distribution is not detected as an efficient reproduction signal.

Figure 7 shows a modification of the optical system of the optical pickup shown in Figure 6. In Figure 7, a unit 40 includes a light source 41 and a light detector 43 which are formed in a single module. A holographic beam splitter 50 is a polarizing hologram with a high optical efficiency, and obtains a high optical efficiency by using a quarter wave plate 60. It is preferable that a polarizing hologram should be replaced by a general hologram in the case when the quarter wave plate 60 is not used. The (light) rays of 650nm from the light source 41 are transmitted through the holographic beam splitter 50 and the quarter wave plate 60, and then become parallel rays by the collimating lens 70. The objective lens 20 or 20' focuses the light incident from the collimating lens 70 on the information recording surface 31A of the thin optical disk 30A or the information recording surface 31B of the thick optical disk 30B, in the form of an optical spot. In the optical pickup shown in the Figure 7, since the objective lens 20 or 20' is the same as that in Figure

6, a detailed description thereof will be omitted. The light reflected from the information recording surface 31A or 31B is finally converged to be focused on the light detector 43 by the hologram beam splitter 50.

Figure 8A shows an optical pickup having an objective lens 20 or 20', two light sources 41 and 45 and a single light detector 43 according to the first and second embodiments of the present invention. The light source 41 emits a laser beam of 650nm and the light source 45 emits a laser beam of 780nm. The 780nm light source should be used for a CD, CD-RW, LD or a CD-R disk, and the 650nm light source should be used for a DVD, CD or CD-RW disk. When the light source 41 is used, the emitted light rays form an optical path shown as a solid line in Figure 8A, in which case the objective lens 20 or 20' is shown as a solid line at position A. When the light source 45 is used, the emitted light rays form an optical path shown as a dotted line, in which case the objective lens 20 or 20' is shown as a dotted line at position B. The optical spot focused on the thick optical disk 30B or the thin optical disk 30A by the objective lens 20 or 20' is the same as that shown in Figure 6.

A beam splitter 46 is a colour separable splitter, which transmits the light supplied from the light source 41 and reflects the light supplied from the light source 45. The light reflected from the beam splitter 46 is incident on a polarizing beam splitter 47. The polarizing beam splitter 47 has an optical characteristic which transmits or reflects linearly polarized beams, which operates with respect to the light of 650nm and 780nm wavelengths. The polarizing beam splitter 47 transmits the light incident from the beam splitter 46, and the transmitted light becomes a circularly polarized beam by a quarter wave plate 60. The circularly polarized beam is focused on the information recording surface of the thin optical disk 30A or the thick optical disk 30B of the objective lens 20 or 20'. The light reflected from the information recording surface passes through the objective lens 20 or 20' and the collimating lens 70 and then becomes linearly polarized light by the quarter wave plate 60. The linearly polarized light is reflected from the polarizing beam splitter 47 and the reflected light is focused into the light detector 43 by the light detection lens 44. The polarizing beam splitter 47 is replaced by a beam splitter which partially transmits and reflects the incident light when the quarter wave plate 60 is not used.

An optical pickup having an objective lens, two light sources, a single light detector, and a plate-type beam splitter 42, can be used as shown in Figure 8B. Figure 8B shows a modification of the optical pickup shown in Figure 8A, by replacing a cube-type beam splitter with a plate-type beam splitter. In addition, the two light sources 41 and 45 face in opposite directions relative to one another and the light detector faces at a 90° angle to the light sources 41 and 45. This is in contrast to the optical pickup shown in Figure 8A, wherein the light sources 41 and 45 face at right angles relative to each other and that the light detector 43 faces in an opposite direction to that of the light source 45 and at a right angle to the light source 41.

Figure 9 shows an optical pickup having an objective lens 20 or 20', two light sources 41 and 45 and two light detectors 83 and 105 according to the first and second embodiments of the present invention. In Figure 9, the light source 41 emits (light) rays having a wavelength of 650nm, the light detector 83 corresponds to the light source 41, and the light source 41 and the light detector 83. Reference numerals 45 and 105 are a light source and a light detector, respectively, for 780nm wavelength light, and 110 is a beam splitter. Other optical elements are the same as those shown in Figures 8A and 8B. Since the optical pickup system shown in the Figure 9 can be understood by a person skilled in the art based on the description provided regarding Figures 8A and 8B, a detailed description thereof will be omitted.

Up to now, the objective lens according to the present invention has been described with reference to the optical pickup. However, it is apparent to one having an ordinary skill in the art that the objective lens according to the present invention can be applied to a microscope or an optical pickup estimating apparatus.

As described above, the optical pickup according to the present invention is compatible with the disks having various different formats irrespective of the thickness or recording density of the disk, and an excellent reading signal can be obtained from the used disk. Also, the objective lens according to the present invention can be manufactured at low costs by using an injection molding. Particularly, when two or more wavelengths are used for optical disk compatibility, an optical pickup can be made using a single objective lens and a single light detector.

While only certain embodiments of the invention have been specifically described herein, it will be apparent that numerous modifications may be made thereto without departing from the scope of the invention.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. An objective lens compatible with at least first and second media having respective different thicknesses and information recording surfaces which store information, the objective lens comprising:
   an inner area, an annular lens area and an outer area centered at a vertex, the annular lens area having a ring shape and dividing the inner area from the outer area, wherein the inner area, the annular lens area and the outer area have aspherical shapes so that, in the case of reading the first medium, light transmitted through the inner area and the outer area is focused into a single light spot by which information is read from the information recording surface of the first medium and light transmitted through the annular lens area is scattered so as not to be focused on the information recording surface of the first medium and, in the case of reading the second medium, the light transmitted through the inner area and the annular lens area is focused into a single light spot by which information is read from the information recording surface of the second medium and light transmitted through the outer lens area is scattered so as not to be focused on the information recording surface of the second medium and wherein the second medium is thicker than the first medium.

2. An objective lens for use in an optical device compatible with at least first and second media having respective different thicknesses and information recording surfaces which store information, the objective lens having a plurality of portions having different optical characteristics, wherein said plurality of lens portions include:

   a first portion to focus a light emitted from a light source onto a given optical medium independent of the thickness of the optical medium;

   a second portion to focus light emitted from the light source onto said optical medium if said optical medium is the first optical medium which has a first predetermined thickness; and

   a third portion to focus said light emitted from said light source onto said optical medium if said optical medium is the second optical medium which has a second predetermined thickness; and

   a surface of the second portion forms a step difference with the surface of one of the first and third portions.

3. An objective lens according to claim 2, wherein the first portion comprises an inner area, the second portion comprises an annular lens area and the third portion comprises an outer area.

4. An objective lens according to claim 1 or 3, wherein a difference ΔZ between a focal distance of the annular lens area and that of the inner area is the same as a defocusing amount determined by the following relationship:

$$\Delta Z=-(2W_{40})/(NA)^2$$

   wherein NA is a numerical aperture in the inner area and W_{40} is a spherical aberration coefficient when the second medium is used.

5. An objective lens according to claim 1, 3 or 4, wherein a surface of the annular lens area forms a step difference for the surface of one of the inner and outer areas.

6. An objective lens according to claim 5, wherein the surface of the annular lens area forms the step difference with the surface of the inner area, wherein the step difference is a value such that a light path difference between the light passing through the inner area and the light passing through the annular lens area is an integer multiple of a wavelength of the light emitted from the light source.

7. An objective lens according to claim 5, wherein the surface of the annular lens area forms the step difference with the surface of the outer area, wherein the step difference is a value such that a light path difference between the

light passing through the inner area and the light passing through the annular lens area is an integer multiple of a wavelength of the light emitted from the light source.

8. An optical pickup in an optical device compatible with at least first and second optical recording media having different thicknesses and including an objective lens according to any of claims 1 to 7, the optical pickup further comprising:

   a first light source to emit light toward said objective lens, the objective lens being arranged to focus the first light emitted from the light source into a single light spot on the information recording surface of a given optical recording medium; and

   a light detector to detect transmitted through the objective lens after being reflected from the information recording surface of the optical recording medium on which the light spot is focused.

9. The optical pickup according to claim 8, wherein the objective lens has a working distance in such a manner that the light transmitted through the inner area is focused into a single light spot having minimum optical aberration on the information recording surface of the second medium during reading of the second medium.

10. An optical pickup according to claim 9, wherein the aspherical surface shape of the inner area is such that the light transmitted through the inner area is focused into a single light spot on the information recording surface of the first optical medium, and the same light is focused into an optical spot having minimum optical aberration on the information recording surface of the second optical medium during reproduction of the second optical medium with said working distance.

11. An optical pickup according to claim 9, wherein the aspherical shape of the annular lens area is such that the light transmitted through the annular lens area is focused into a single light spot having no spherical aberration on the information recording surface of the second optical recording medium during reproduction of the second optical recording medium having a thick substrate.

12. An optical pickup according to any of claims 8 to 11, further comprising at least a second light source, said second light source emitting light of a different wavelength to light emitted from the first light source.

13. An optical pickup according to claim 12, further comprising a beam splitter having a beam splitting characteristic with respect to each of the plurality of the beams respectively emitted from the first light source and the at least second light source.

14. An objective lens according to any of claims 1 or 3 to 7 or an optical pickup device as claimed in any of claims 8 to 13, wherein the inner area of the objective lens has a numerical aperture value NA which satisfies the following equation:

$$0.8\lambda/NA \sim \text{spot size}$$

   where λ represents the wavelength of light emitted from the light source and the spot size is a size of a spot that the light passing through the objective lens forms on a disk.

15. The objective lens or optical pickup as claimed in claim 14, wherein the objective lens has a defocused coefficient W_{20} which minimises an optical aberration according to the following equation:

$$W_{20}=-W_{40},$$

   wherein W_{40} is a spherical aberration coefficient produced due to a difference in the first and second thicknesses.

16. The optical pickup or objective lens as claimed in claim 15, wherein a defocus amount ΔZ of the objective lens follows the following equation:

$$\Delta Z=-(2W_{40})/(NA)^2,$$

wherein NA is a numerical aperture value of the inner area.

17. An optical pickup as claimed in any of claims 8 to 16, further comprising: a separation unit to separate incident light transmitted from said light source from light reflected by the disk.

18. An optical pickup as claimed in claim 17, further comprising:

    a collimating lens disposed in a linear path between the objective lens and the light detector to collimate the incident light separated by the separation unit and to transmit the reflected light from the disk towards the separation unit; and

    a light detection lens to focus the reflected light passing through the separation unit toward the detector.

FIG. 1A

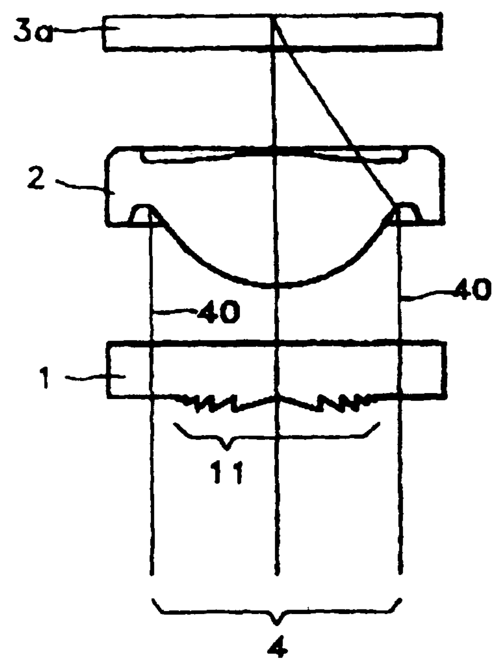


FIG. 1B

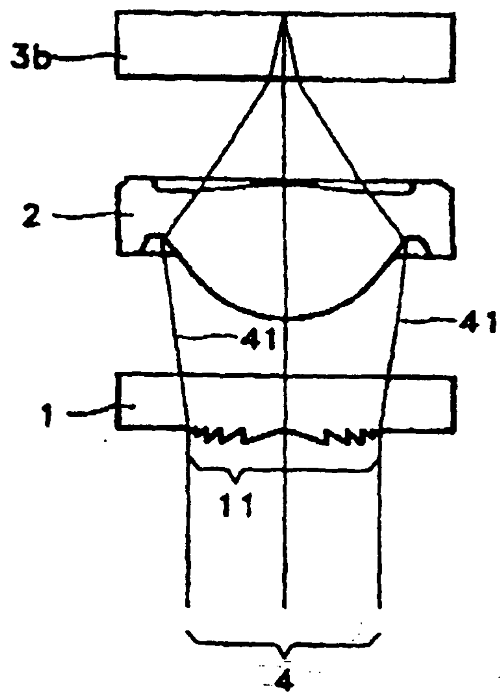


FIG. 2A

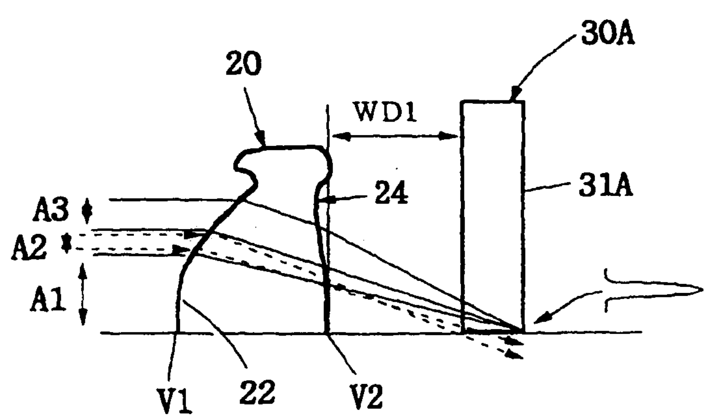


FIG. 2B

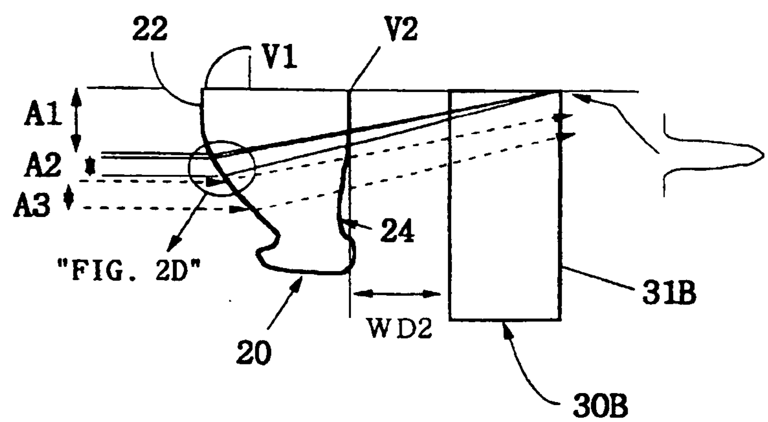


FIG. 2C

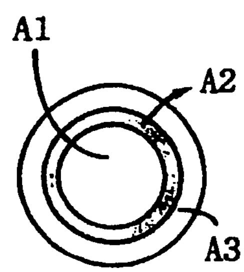


FIG. 2D

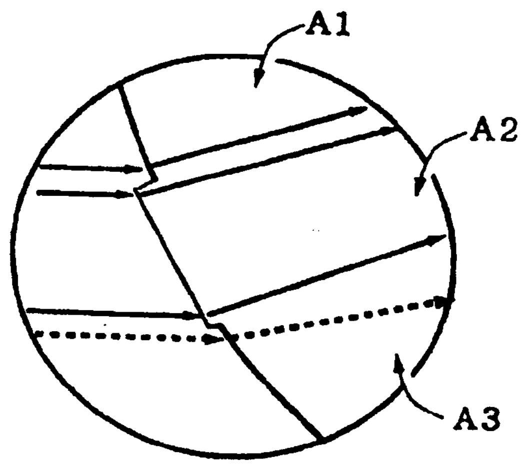


FIG. 3A

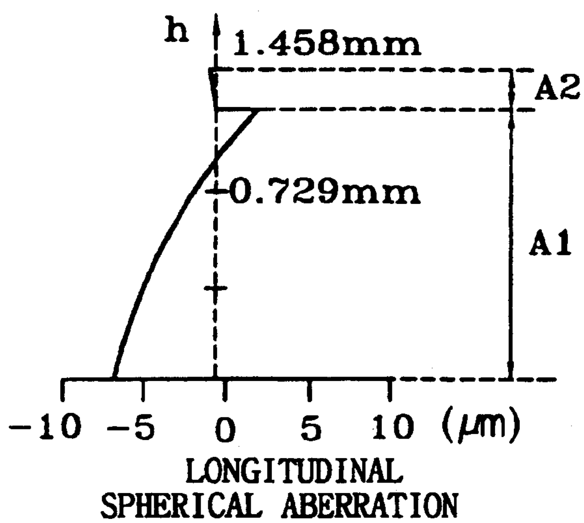


FIG. 3B

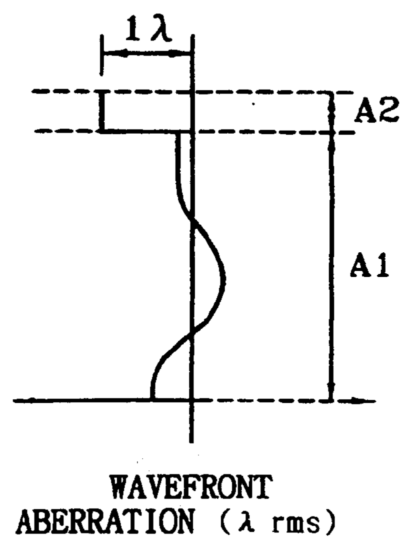


FIG. 4

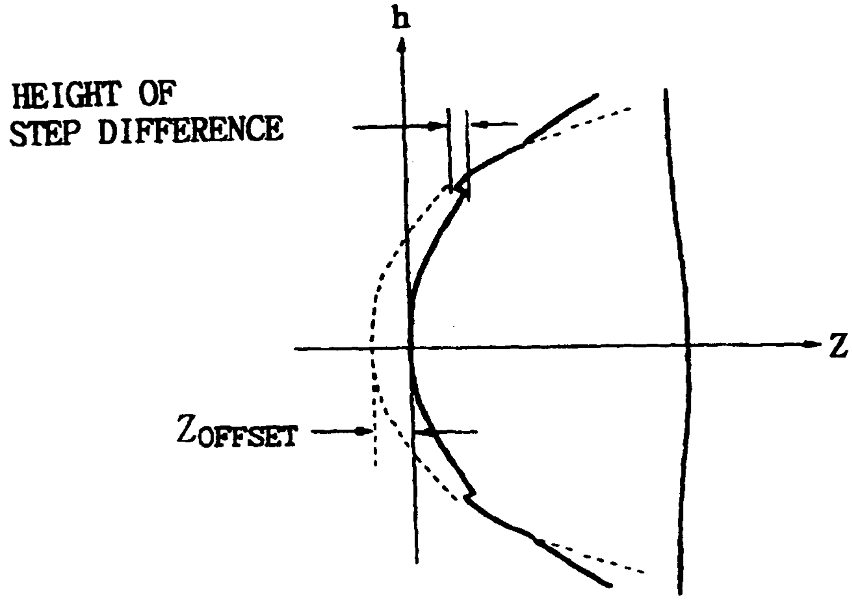


FIG. 5

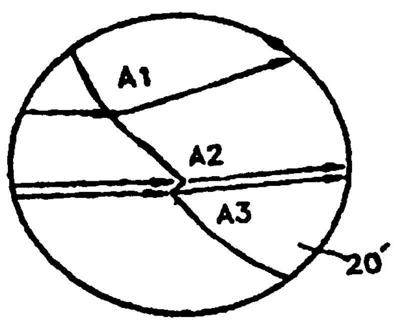


FIG. 6

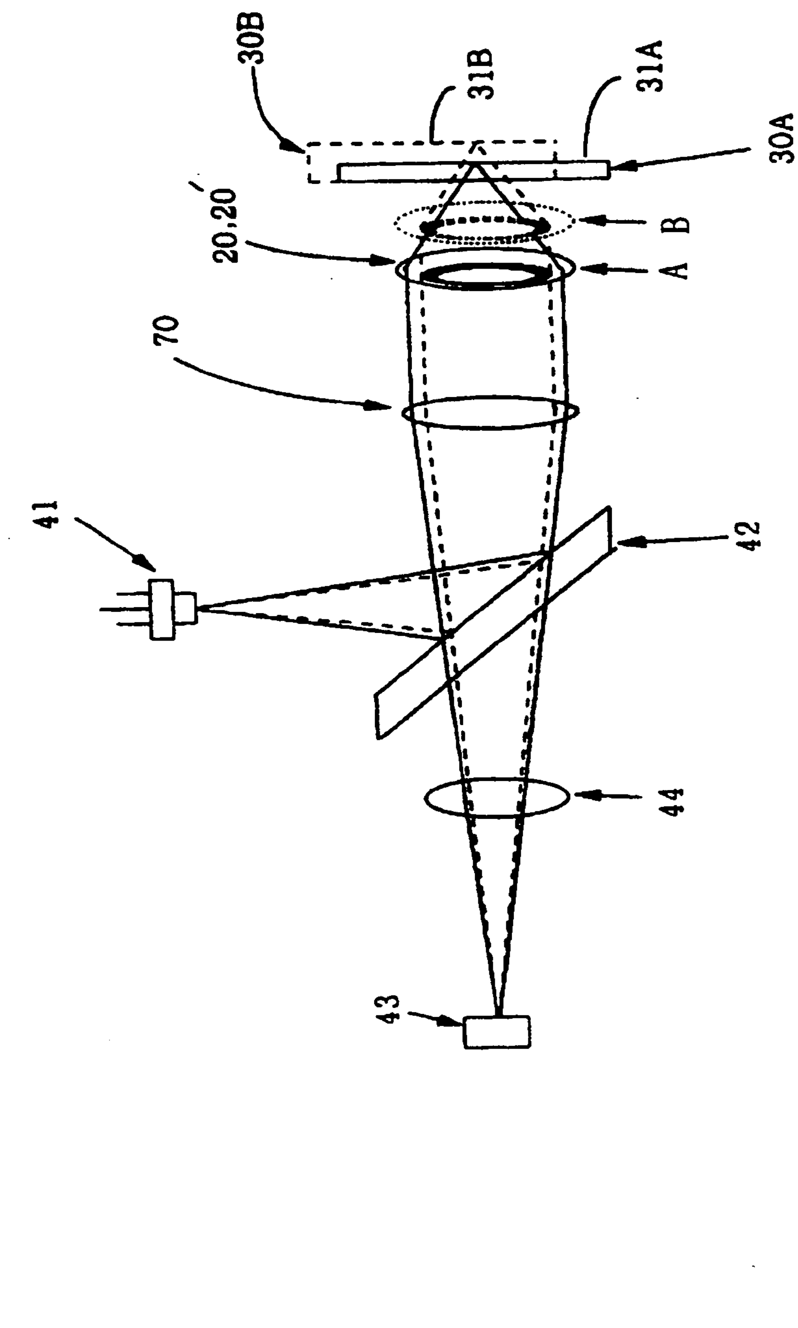


FIG. 7

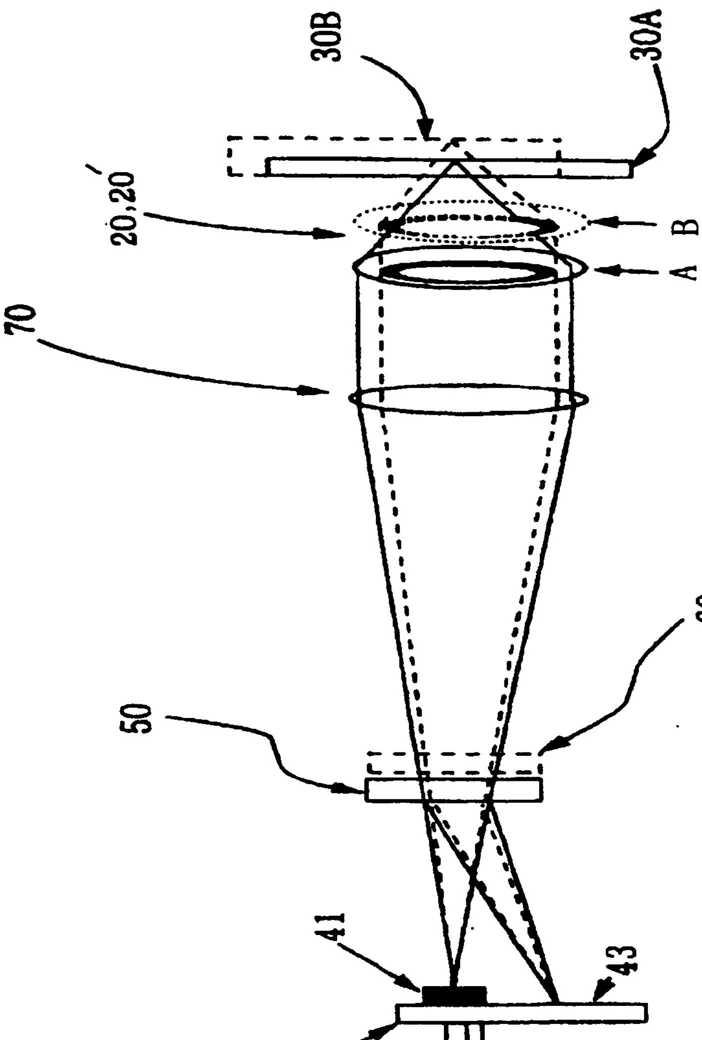


FIG. 8A

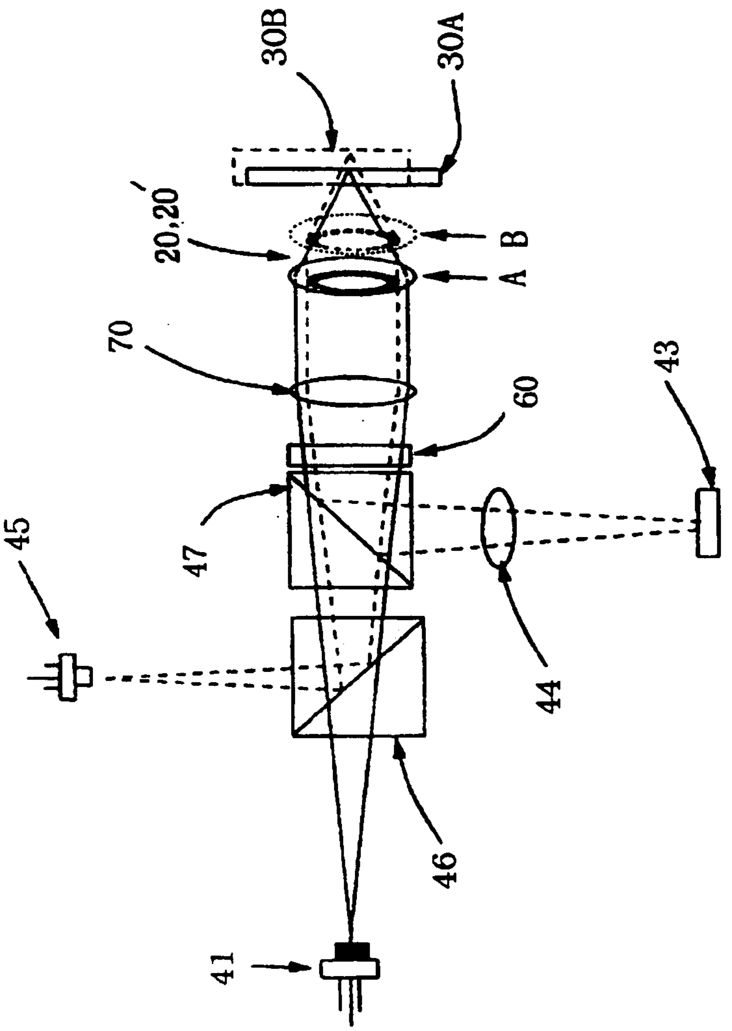


FIG. 8B

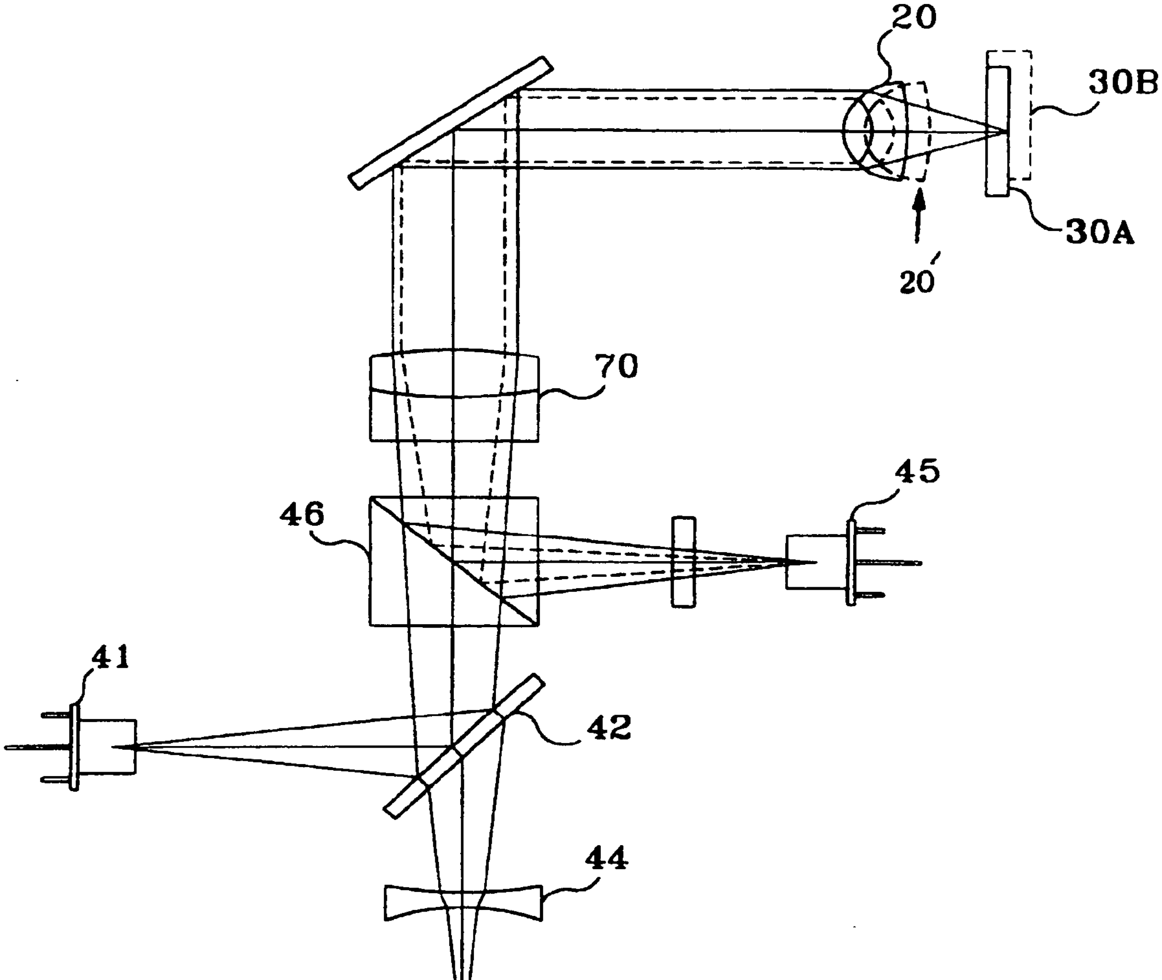


FIG. 9

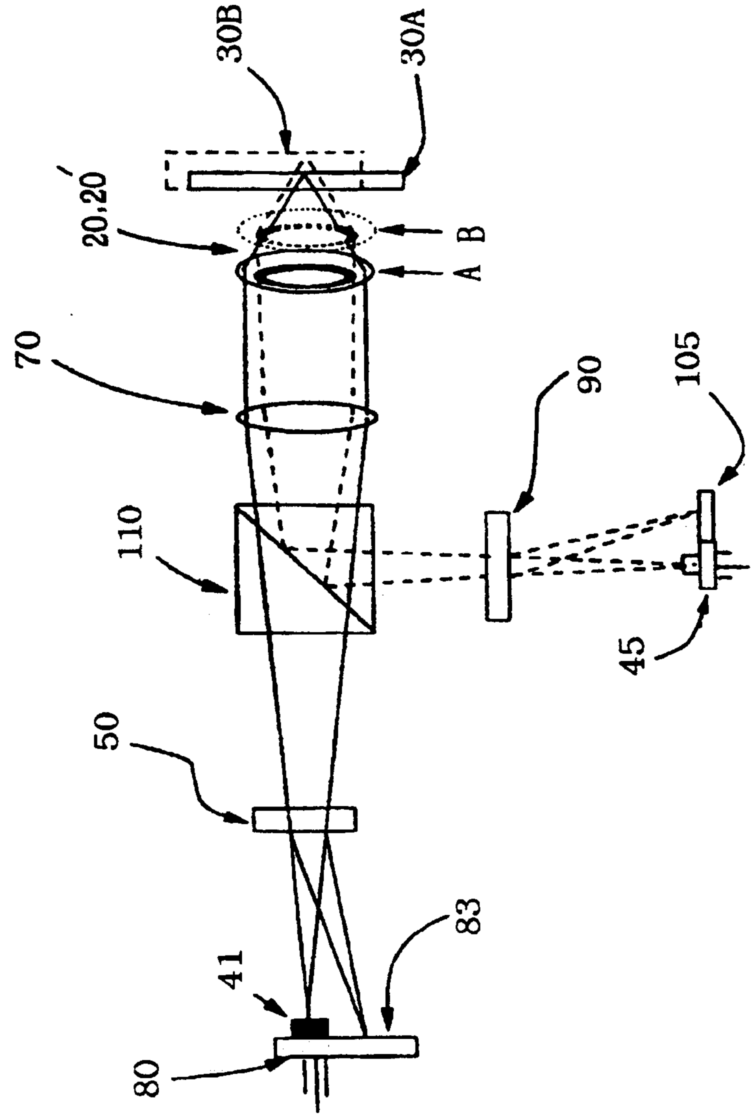


FIG. 10

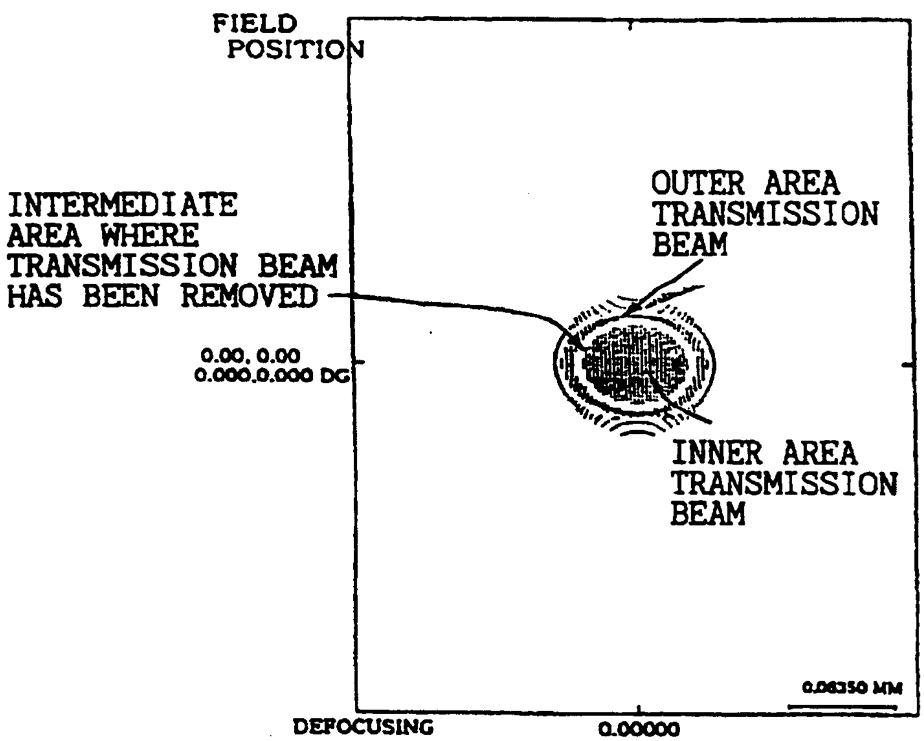
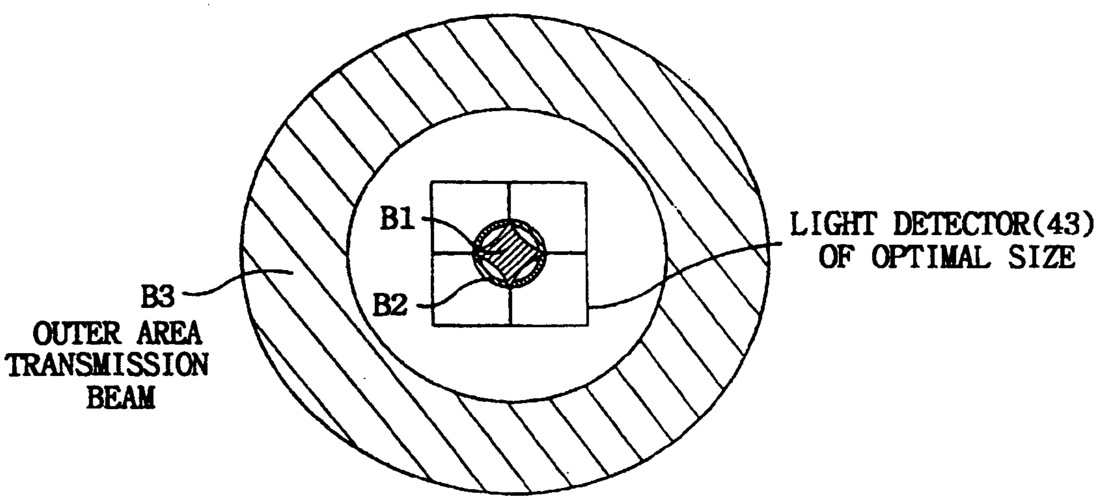

FIELD
POSITION
INTERMEDIATE
AREA WHERE
TRANSMISSION BEAM
HAS BEEN REMOVED
OUTER AREA
TRANSMISSION
BEAM
0.00, 0.00
0.000,0.000 DG
INNER AREA
TRANSMISSION
BEAM
0.06350 MM
DEFOCUSING
0.00000

FIG. 11


B1
B2
B3
OUTER AREA
TRANSMISSION
BEAM
LIGHT DETECTOR(43)
OF OPTIMAL SIZE

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

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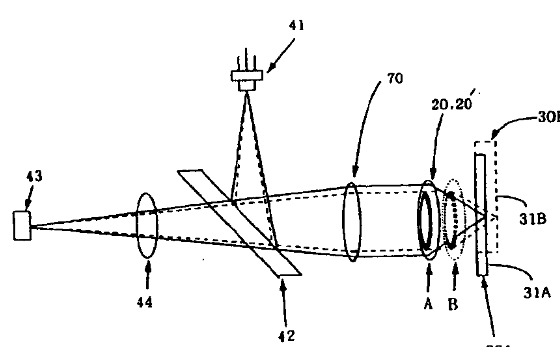
(54) Optical pickup having an objective lens compatible with a plurality of optical disk formats

(57) An optical pickup compatible with a plurality of optical recording media each using light of a different wavelength. The optical pickup includes at least one light source (41), an objective lens (20, 20') having a function of focusing light emitted from the light source (41) into the optimal light spot on an information recording surface of one of the plurality of the optical recording media (30), and a light detector (43) to detect light transmitted through the objective lens (20, 20') after being reflected from the information recording surface of the optical recording medium (30) on which the light spot is formed. The objective lens (20, 20') has an inner area, an annular lens area and an outer area such that the annular lens area divides the inner area from the outer area and has a ring shape centered at a vertex. The inner area, the annular lens area and the outer area have aspherical surface shapes to focus light transmitted through the inner area and the outer area into a single light spot by which information can be read from the information recording surface of a relatively thin first optical recording medium (30A) and scatter light transmitted through the annular lens area located between the inner area and the outer area so that information cannot be read from the information recording surface of the first optical recording medium (30A), during reproduction of the first optical recording medium. The inner area and the annular lens area transmit light into a single light spot by which information can be read from the information recording surface of a relatively thick second optical recording medium (30B) and scatters light transmitted through the outer lens area so that information cannot be read from the information recording surface of the second optical recording medium (30B), during reproduction of the second optical recording medium (30B).

FIG. 6



EP 0 859 356 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 1050

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
E	EP 0 838 812 A (KONISHIROKU PHOTO IND) 29 April 1998 * page 5, line 16 - page 8, line 11; figures 1-3 *	1-3,5, 8-14,17, 18	G11B7/00 G11B7/135 G11B7/125
P,X	EP 0 776 004 A (KONISHIROKU PHOTO IND) 28 May 1997 * page 2, line 57 - page 3, line 4 * * page 49, line 6 - page 50, line 16; figures 57-63 *	1-3, 5-11,14, 17,18	
D,X	PATENT ABSTRACTS OF JAPAN vol. 096, no. 003, 29 March 1996 & JP 07 302437 A (TOSHIBA CORP), 14 November 1995 * abstract *	1-3,5, 8-11,14	
A	EP 0 742 554 A (SANYO ELECTRIC CO) 13 November 1996 * column 9, line 30 - column 9, line 55; figure 6 *	1-3, 8-14,17, 18	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G11B
A	EP 0 731 458 A (SONY CORP) 11 September 1996 * page 3, line 54 - page 5, line 42; figures 3,4,9 *	1-3, 8-11,14, 17,18	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	16 November 1998	Moje, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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